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(54) **SIMULTANEOUS FORWARD LINK BEAM FORMING AND LEARNING METHOD FOR MOBILE HIGH RATE DATA TRAFFIC**

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(58) Field of Search 455/561, 562, 455/517, 512, 525; 370/334, 329, 338, 347, 349, 468, 252

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,471,647	* 11/1995	Gerlach et al.	455/63
5,634,199	5/1997	Gerlach et al.	455/63
5,666,655	* 9/1997	Ishikawa et al.	455/512
5,818,385	* 10/1998	Bartholomew et al.	342/372
6,014,570	1/2000	Wong et al.	455/500
6,127,988	* 10/2000	McNichol et al.	343/844

OTHER PUBLICATIONS

M.C. Wells, "Increasing the capacity of GSM cellular radio using adaptive antennas", IEE (UK) Proc. On Comm. vol. 143, No. 5, Oct. 1996, pp. 304–310.

S. Anderson, B. Hagerman, H. Dam, U. Forssen, J. Karlsson, F. Kronestedt, S. Mazur and K. Molinar, "Adaptive Antennas for GSM and TDMA Systems", IEEE Personal Communications, Jun. 1999, pp. 74–86.

* cited by examiner

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(57) **ABSTRACT**

Disclosed is a base station of a wireless communications system including an adaptive antenna array and beam forming means for forming simultaneous multiple forward link beams. Preferably mobile stations are separated into groups of mobile stations corresponding to a maximum number of simultaneous forward link beams for determining which of said groups can be served by compatible simultaneous forward link beams. Preferably, if mobiles remain outside of a compatible group, the number of simultaneous forward link beams is increased and grouping of the mobile stations is repeated until all the mobile stations are included in compatible groups. Preferably simultaneous data beams are formed to mobiles of a said group during a time interval accorded to said group, such that every mobile station receives service data during a full cycle of said time intervals at a rate equal to or in excess of a target service data rate for that mobile.
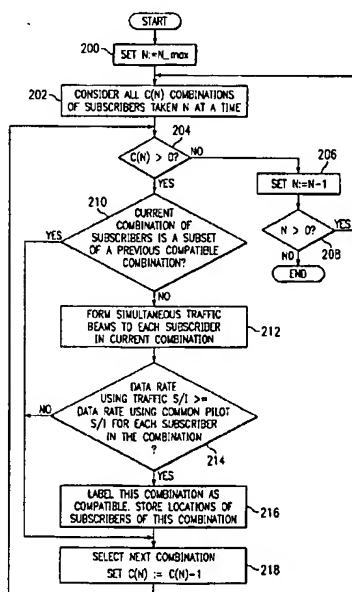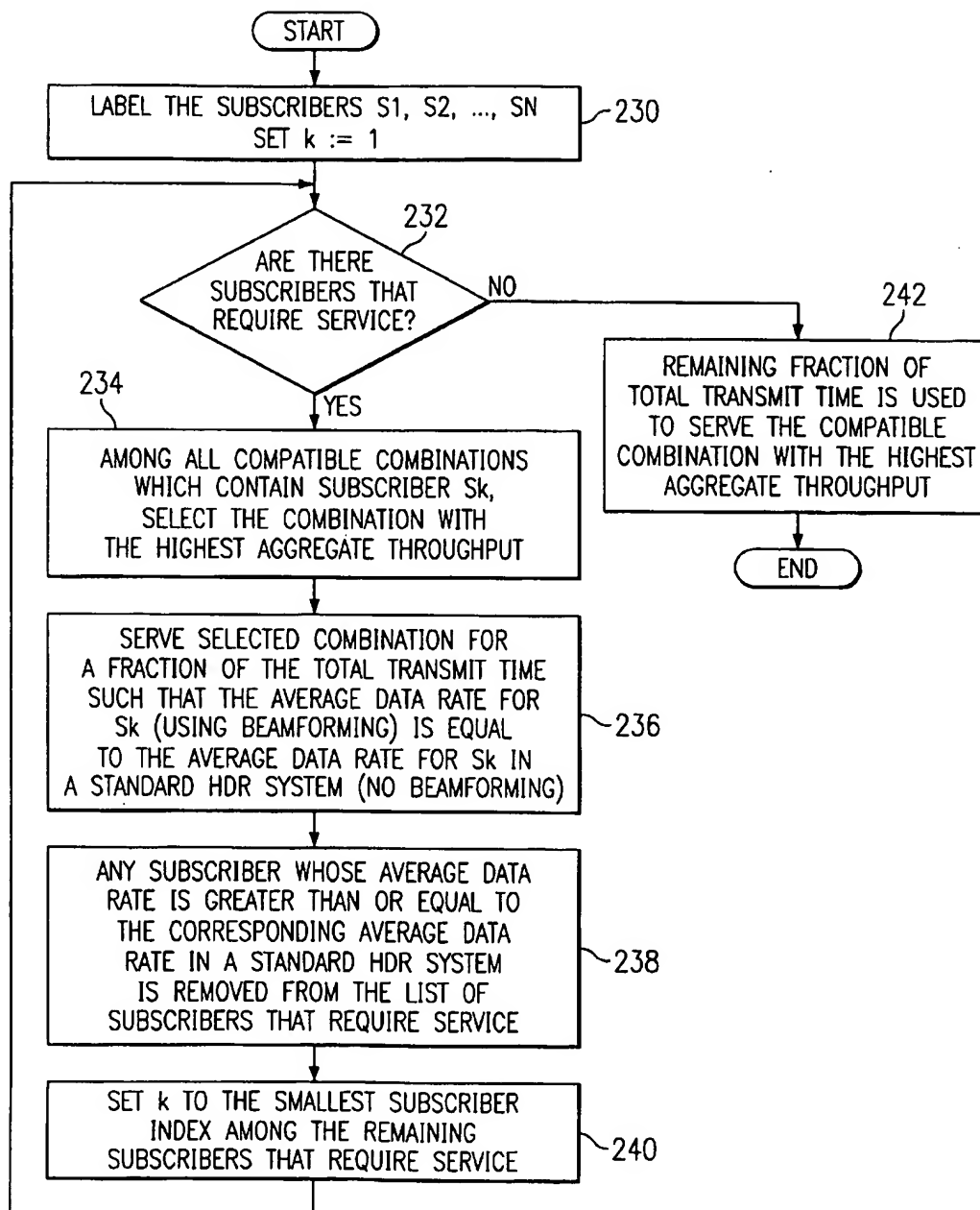
20 Claims, 6 Drawing Sheets

FIG. 9

START

LABEL THE SUBSCRIBERS S1, S2, ..., SN
SET k := 1 —230

232
ARE THERE SUBSCRIBERS THAT REQUIRE SERVICE? —NO

234

AMONG ALL COMPATIBLE COMBINATIONS
WHICH CONTAIN SUBSCRIBER Sk,
SELECT THE COMBINATION WITH
THE HIGHEST AGGREGATE THROUGHPUT

YES

242

REMAINING FRACTION OF
TOTAL TRANSMIT TIME IS USED
TO SERVE THE COMPATIBLE
COMBINATION WITH THE HIGHEST
AGGREGATE THROUGHPUT

END

SERVE SELECTED COMBINATION FOR
A FRACTION OF THE TOTAL TRANSMIT TIME
SUCH THAT THE AVERAGE DATA RATE FOR
Sk (USING BEAMFORMING) IS EQUAL
TO THE AVERAGE DATA RATE FOR Sk IN
A STANDARD HDR SYSTEM (NO BEAMFORMING) —236

ANY SUBSCRIBER WHOSE AVERAGE DATA
RATE IS GREATER THAN OR EQUAL TO
THE CORRESPONDING AVERAGE DATA
RATE IN A STANDARD HDR SYSTEM
IS REMOVED FROM THE LIST OF
SUBSCRIBERS THAT REQUIRE SERVICE —238

SET k TO THE SMALLEST SUBSCRIBER
INDEX AMONG THE REMAINING
SUBSCRIBERS THAT REQUIRE SERVICE —240

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DOCUMENT-IDENTIFIER: US 6330460 B1

TITLE: Simultaneous forward link beam forming and learning
                method for mobile high rate data traffic

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Brief Summary Text - BSTX (6):
    The CDMA air-interface calls for modulation of each carrier with a unique
pseudorandom (pseudo-noise) code. As the CDMA users simultaneously occupy the
same frequency band, the aggregate **data signal transmitted** by a fixed base
station (forward link) is noise-like. A common pilot tone is transmitted to
all mobiles within the effective service area of the base station. Individual
signals are extracted at the mobile by correlation processing timed by the
pilot tone.

Brief Summary Text - BSTX (12):
    As shown in FIG. 1 forward link **packet transmissions** are time-multiplexed
and transmitted at a full base station power level, but with data rates and
time slot durations which vary according to base-to-mobile (user) channel
(forward link maximum data rate) conditions. When a mobile's data queue is
empty, the base station periodically broadcasts very brief pilot and control
burst information, thereby reducing interference to adjacent cells. In the
proposed HDR scheme, a minimum data rate is set at 76.8 kbps using 128 byte
packets and QPSK **modulation, and a maximum data rate** is set at 2457.6 kbps
using 512 byte packets and 16QAM modulation.

Detailed Description Text - DETX (8):
    The beam forming strategy in accordance with the present invention is to
form as many simultaneous beams within each time slot as possible of a sector
service cycle, since an increase in the number of simultaneous beams increases
the aggregate data throughput rate of the service sector, e.g., exemplary
sector SS1. As shown in FIG. 4, each simultaneously formed **beam most
preferably has a beam width** BW which envelopes the recipient mobile and
provides a tolerance or operating range to provide continuing service as the
mobile moves through the particular service sector SS.

Detailed Description Text - DETX (15):
    At lower data rates a robust four level modulation format, such as
quadrature phase shift keying (QPSK), is preferred. At high data rates it is
practical to use a larger constellation modulation format, such 8-level PSK
or 16-level quadrature amplitude modulation (QAM). At the **higher data rates** it
is important to maintain the dedicated pilot at a minimum effective level.
Thus, as shown in FIG. 7, the dedicated pilot power level falls at a relatively
steep rate in relation to increasing data **rate for QPSK modulation,** and
thereafter falls at a much more shallow rate in relation to increasing data
rate for 8 PSK modulation and 16 QAM.

Detailed Description Text - DETX (18):

Combinations of mobiles suitable for receiving simultaneous transmission are
determined based on the locations and data rates of the particular mobile
stations relative to the base station (the base station accurately determines
angle and radius for each mobile as part of the reverse link and forward link
beam forming process). Particular results depend on the actual propagation
environments and parameters applicable to each particular service sector. A
combination of mobiles is said to be "compatible" for simultaneous **transmission
if the data** rate achievable with the particular combination is equal to or
greater than the data rate achievable using a common pilot, conventional HDR
data rate without simultaneous beam forming for each mobile of the combination.
In this regard, compatible combinations which are subsets of other compatible
combinations are discarded as unnecessary. In statistically rare circumstances
a compatible combination might comprise a single active mobile station, in
which case the aggregate data rate for such a single unit group would equal the
conventional HDR data rate.

Detailed Description Text - DETX (24):

In the conventional HDR method, a maximum of 29 mobiles can be served at any
given time within a service sector of a CDMA wireless communications system.
In order that the new method provide a data rate for every mobile which is at
least equal to the conventional HDR data rate, the base station first considers
a first mobile presently having the lowest data rate, and considers all
compatible combinations which include this first mobile, picking the
combination which results in the highest aggregate data throughput. The
selected combination is served for a fraction of the total **transmit time such
that the average data** rate for the first mobile is at least equal to the data
rate of the conventional HDR system. While this first mobile receives forward
link data at a rate not less than the conventional HDR data rate, the other
mobiles within the combination receive forward link data at data rates well in
excess of the conventional HDR base line rate. This method achieves a desired
high base station aggregate data throughput for this particular combination.
Then, a second mobile having the next lowest data rate and which is not a
member of the first combination is considered along with other mobiles awaiting
service by the base station, and a combination which results in the highest
base station aggregate data throughput is selected. The second mobile and the
other mobiles of the second combination receive forward link data transfers
during a second slot which represents another fraction of the total transmit
time sufficient to enable the second mobile to receive forward link data at or
above the base line conventional HDR data rate. This process of forming
compatible combinations and sending forward link data to the mobiles of each
combination during fractions of total transmit time continues until all mobiles
within the service sector have been serviced.

Detailed Description Text - DETX (25):

After all of the mobiles have been grouped into compatible combinations and
serviced via simultaneous beams as explained above, a fraction of total
transmit time will typically remain available for further use. One approach
may be to use the remaining time to serve the combination of mobiles having the
highest aggregate data throughput. This approach will result in the highest
overall service sector aggregate data rate, and some mobiles will receive data
at exceptionally high data rates. An alternative approach which results in
lower overall aggregate data rate, but which more equitably services all
mobiles is to serve each compatible combination in proportion to the fraction
of time previously given to that combination. Within the conventional HDR
approach, mobiles closer to the base station typically receive data at the

highest data rates. In contrast to conventional HDR, in the approach of the present invention not only do the mobiles closer to the base receive **higher aggregate data rates,** but also the mobiles which may be more distant from the base station receive **higher aggregate data rates,** depending upon their angle and distance from the base station as explained above.

Detailed Description Text - DETX (33):

Table 1 presents data from a simulation using beam forming with a dedicated pilot. The path loss exponent is a quantification of path loss between the base station and the mobile station. The standard deviation of the lognormal shadowing represents a shadowing parameter between the base station and the mobile station. The angle spread range represents assumed angle spread at the mobile station, with an angle range of 10.degree. to 60.degree. conservatively assumed for stations close to the base station, and a range of 0.degree. to 30.degree. aggressively assumed for stations at a relatively distant location relative to the base station. The next column, HDR throughput represents a standard base line data throughput for the assumed conditions based on the conventional HDR standard. This forms a base line with a latency ratio of 5. The next column, Gain AAA(1) represents data throughput gain in accordance with the new method in which remaining time is given to the best combination. In the first row example the data rate gain is 3.4 times the base rate of 563 kbps. Since some mobiles will get significantly **higher data rates** when the remaining time is given to the best compatible combination over comparable mobiles within a conventional HDR paradigm, the latency ratio becomes very high, e.g., 112. When the second method (2) is used for allocating excess time equitably across all compatible combinations, rather than solely to the fastest compatible combination (1), the first row examplary data rate gain is 3 times greater than conventional HDR and the latency ratio falls to 82, denoting more equity in distribution of service among all of the mobiles being serviced in the service sector.